NASA Plant Research for Life Support in Space

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Human Life Support Requirements:

Inputs

	Daily Rqmt.	(% total mass)
Oxygen	0.83 kg	2.7%
Food	0.62 kg	2.0%
Water (drink and food prep.)	3.56 kg	11.4%
Water (hygiene, flush laundry, dishes)	26.0 kg	83.9%
TOTAL	**31.0 kg**	

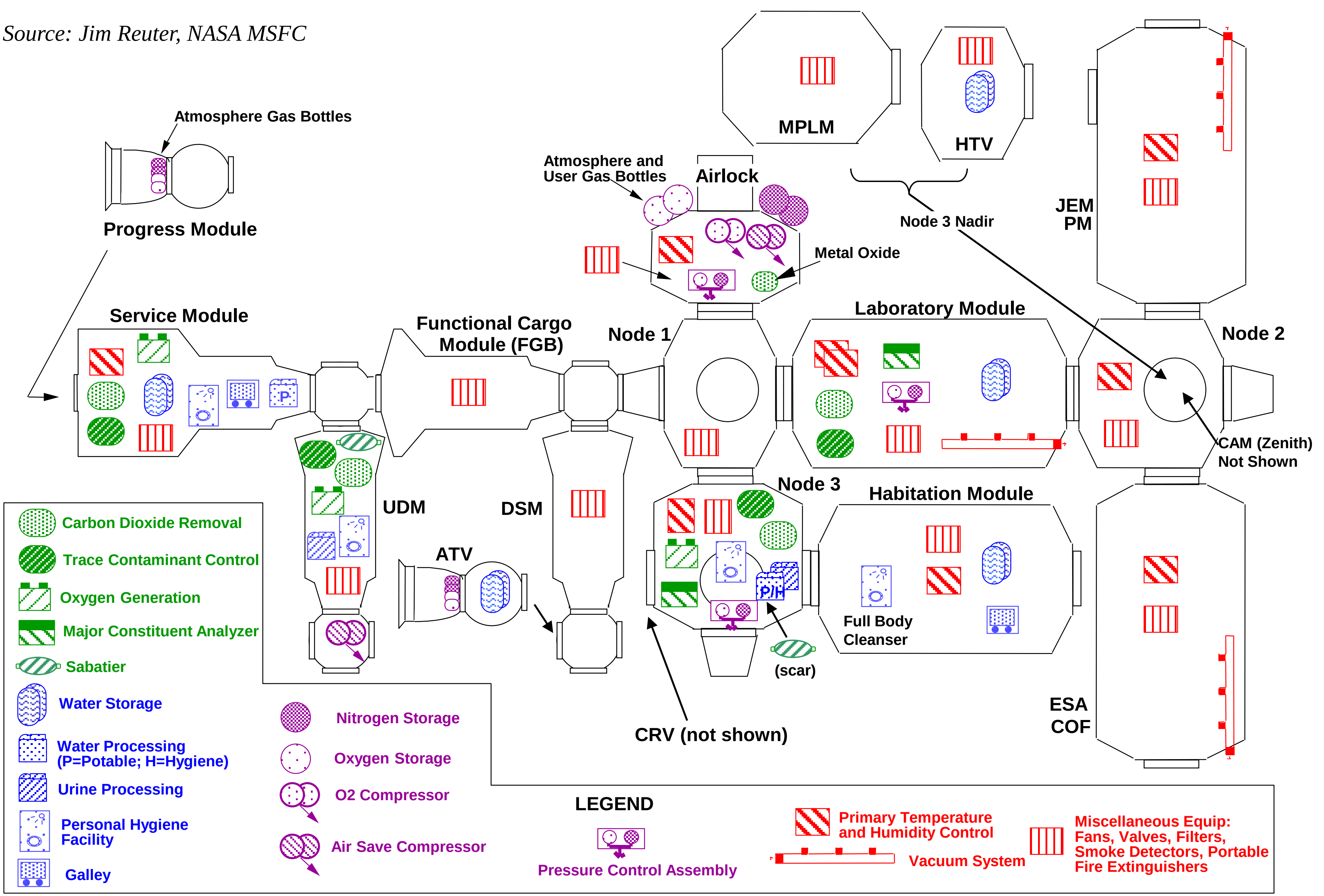
Outputs

	Daily	(% total mass)
Carbon dioxide	1.00 kg	3.2%
Metabolic solids	0.11 kg	0.35%
Water	29.95 kg	96.5%
(metabolic / urine		12.3%)
(hygiene / flush		24.7%)
(laundry / dish		55.7%)
(latent		3.6%)
TOTAL	**31.0 kg**	

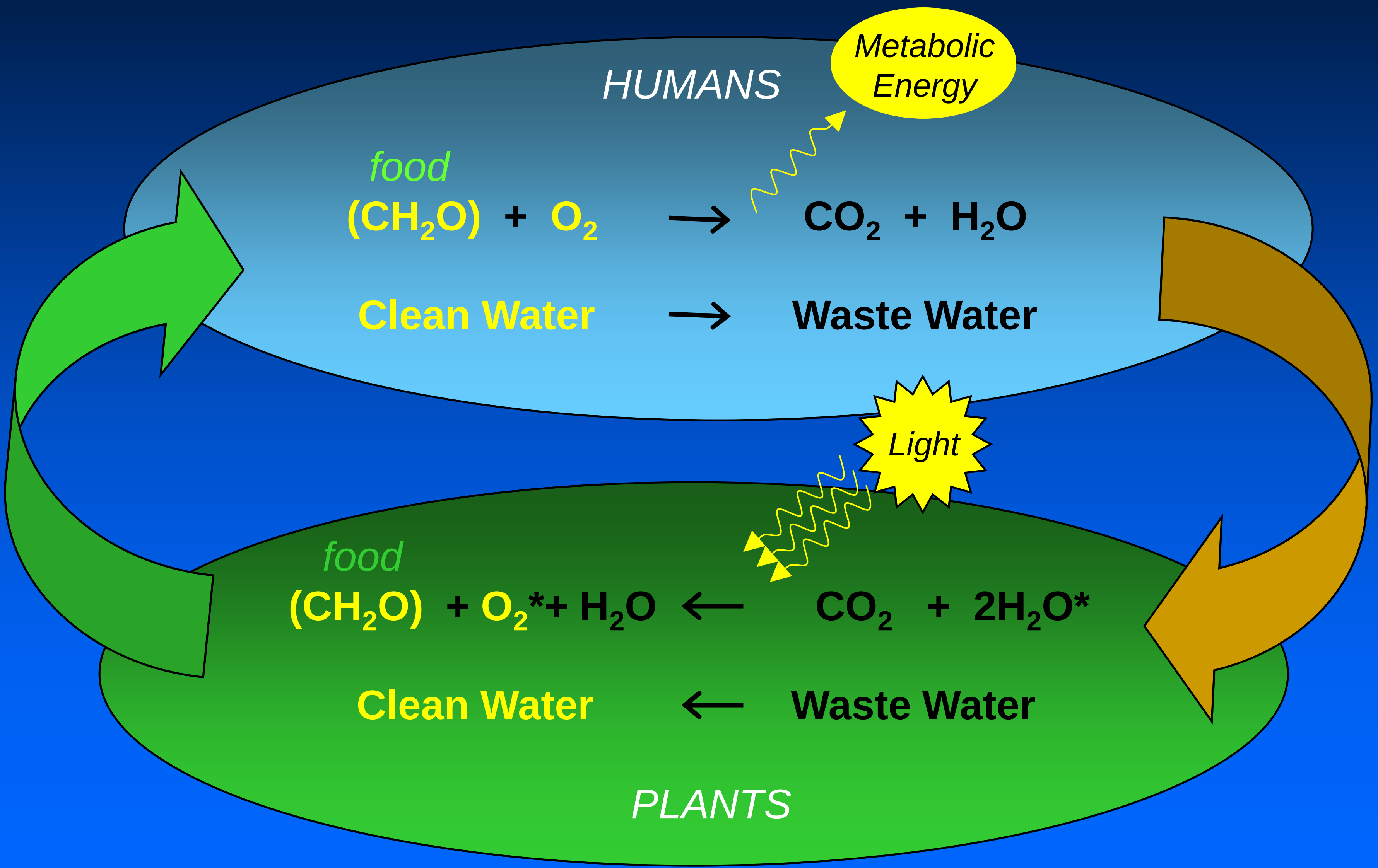
Source: NASA SPP 30262 Space Station ECLSS Architectural Control Document
Food assumed to be dry except for chemically-bound water.

International Space Station Life Support Systems

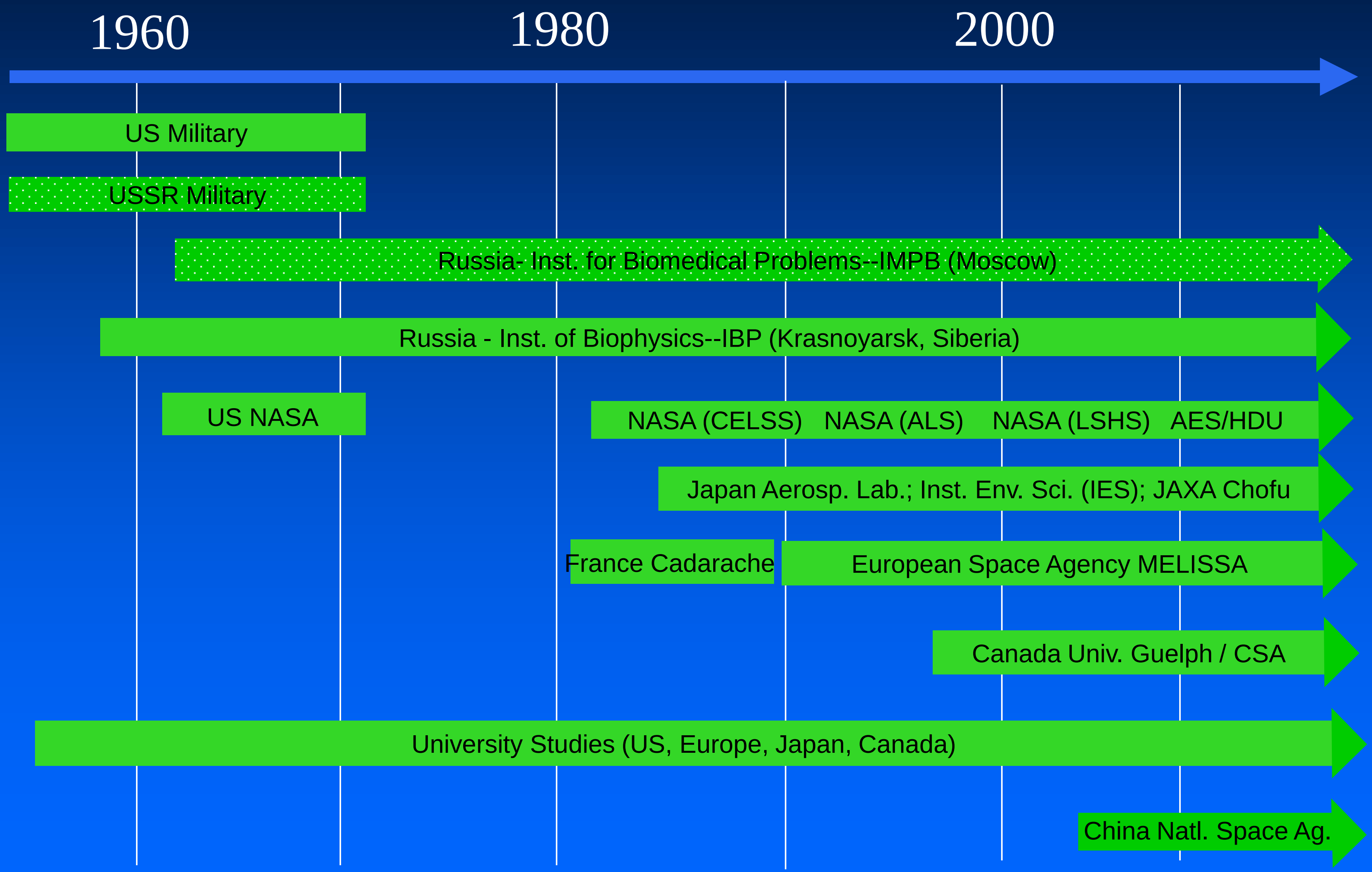
Source: Jim Reuter, NASA MSFC



Plants for "Bioregenerative" Life Support



Bioregenerative Life Support Testing Around the World



Crop Considerations for Space

- High yielding and nutritious (CHO, protein, fat, micronutrients)
- High harvest index (edible / total biomass)
- Horticultural requirements
  - planting, watering, harvesting, pollination, propagation
- Environmental requirements
  - lighting, temperature, mineral nutrition, CO_2
- Processing requirements
- Dwarf or low growing types

Some Crops for Life Support

Tibbitts and Alford [a]	Hoff, Howe, and Mitchell [b]	Salisbury and Clark [c]	Russian BIOS-3 Testing [d]
Wheat	Wheat	Wheat	Wheat
Soybean	Potato	Rice	Potato
Potato	Soybean	Sweetpotato	Carrot
Lettuce	Rice	Broccoli	Radish
Sweetpotato	Peanut	Kale	Beet
Peanut	Dry Bean	Lettuce	Nut Sedge
Rice	Tomato	Carrot	Onion
Sugar Beet	Carrot	Canola	Cabbage
Pea	Chard	Soybean	Tomato
Taro	Cabbage	Peanut	Pea
Winged Bean		Chickpea	Dill
Broccoli		Lentil	Cucumber
Onion		Tomato	Salad spp.
Strawberry		Onion	
		Chili Pepper	

[a] Tibbitts and Alford (1982); [b] Hoff, Howe, and Mitchell (1982); [c] Salisbury and Clark (1996);
[d] Gitelson and Okladnikov (1994)—diet also included supplemental animal protein and sugar.

Crop Selection and Breeding for Space
(Utah State University)

Selection of Existing Rice Genotypes

Wheat Breeding for Short Growth and High Harvest Index

'Apogee' Wheat 'Perigee' Wheat

Genetic Engineering Tools

Overexpression of FT flowering gene in plums (USDA researchers) resulted in dwarf growth habit and early flowering

Water and Nutrients for Growing Crops

Recirculating Hydroponics

Conserve Water & Nutrients
Eliminate Water Stress
Optimize Mineral Nutrition
Facilitate Harvesting

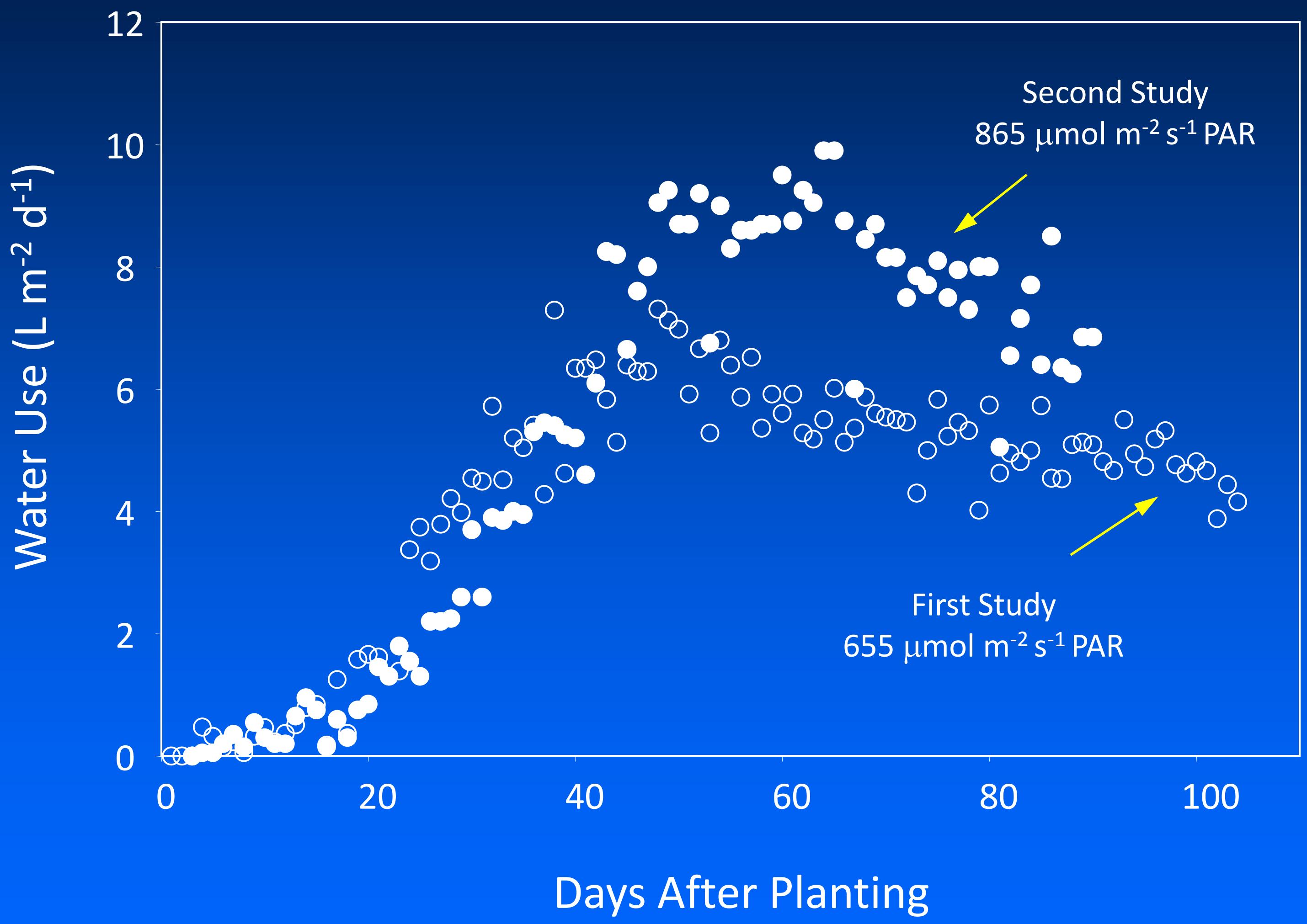
Wheeler et al., 1999. Acta Hort.

Root Zone Crops in Nutrient Film Technique (NFT)

Wheeler et al., 1990. Amer. Potato J. 67:177-187; Mackowiak et al. 1998. HortScience 33:650-651

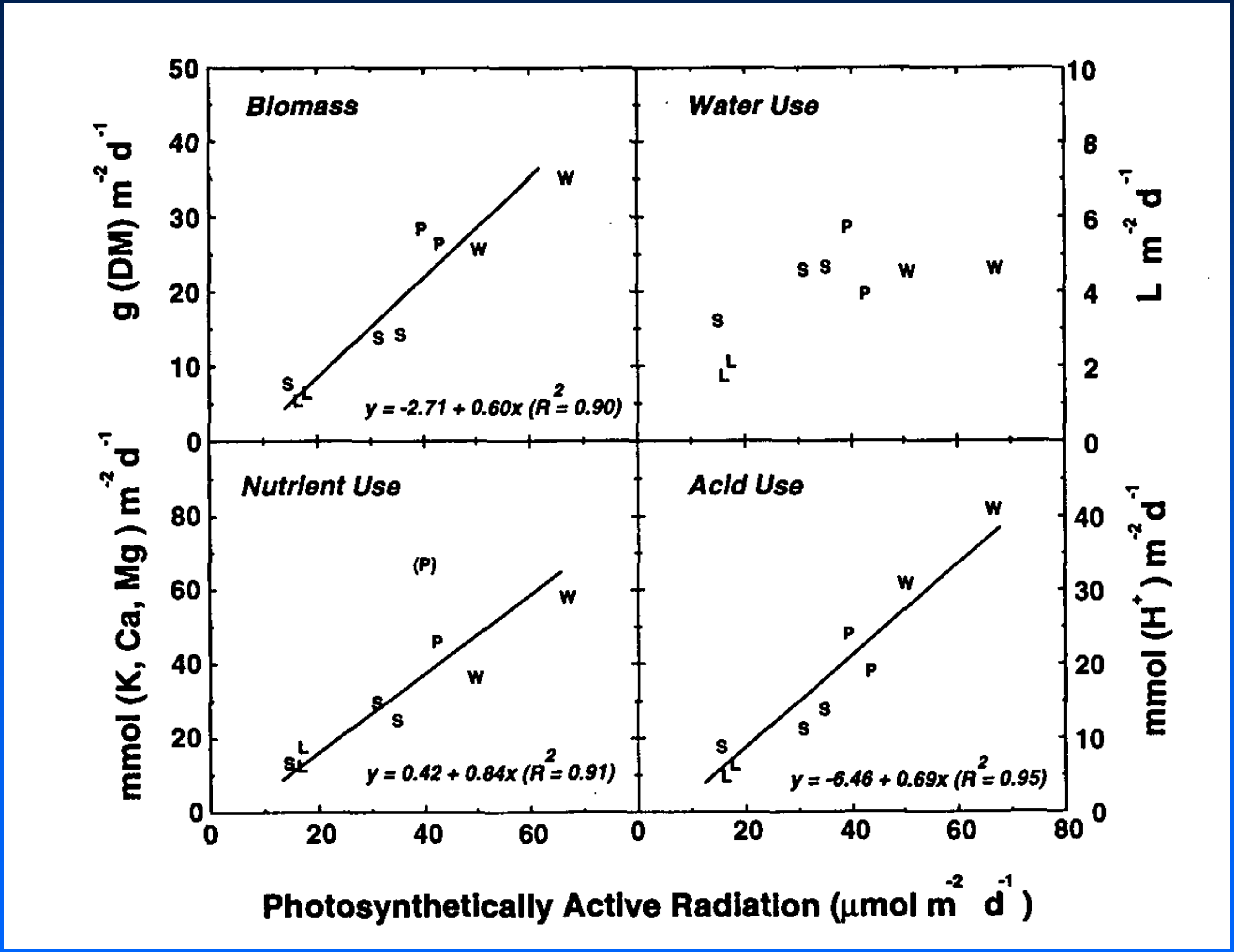
Fig. 7

Evapotranspiration from Plant Stand (potato)



Wheeler. 2006. Potato Research 49:67-90.

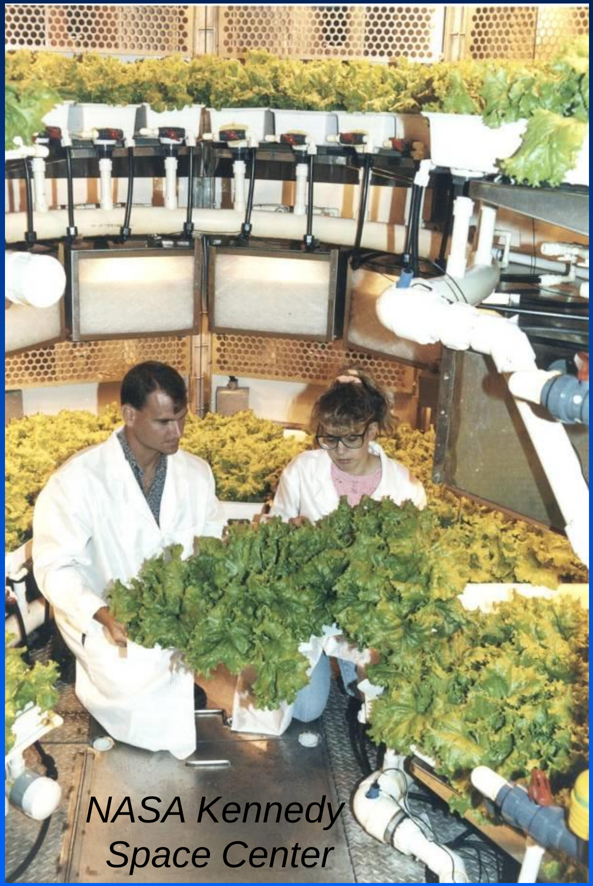
Water, Nutrient, and pH Control

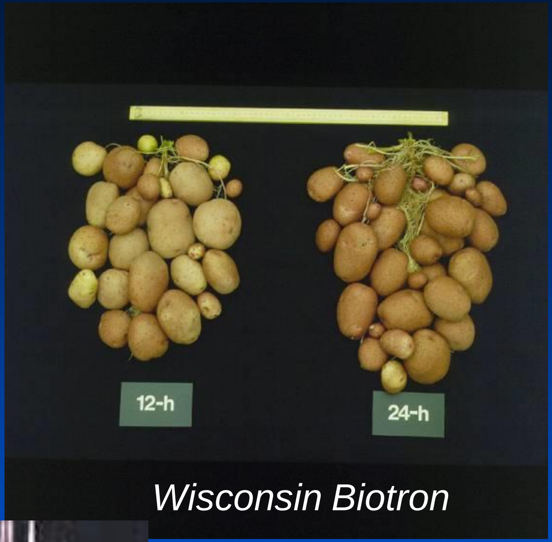


Wheeler et al. 1999. Acta Hort.

High Yields from NASA Sponsored Studies

Wheat - 3-4 x World Record
Potato - 2 x World Record
Lettuce-Exceeded Commercial Yield Models

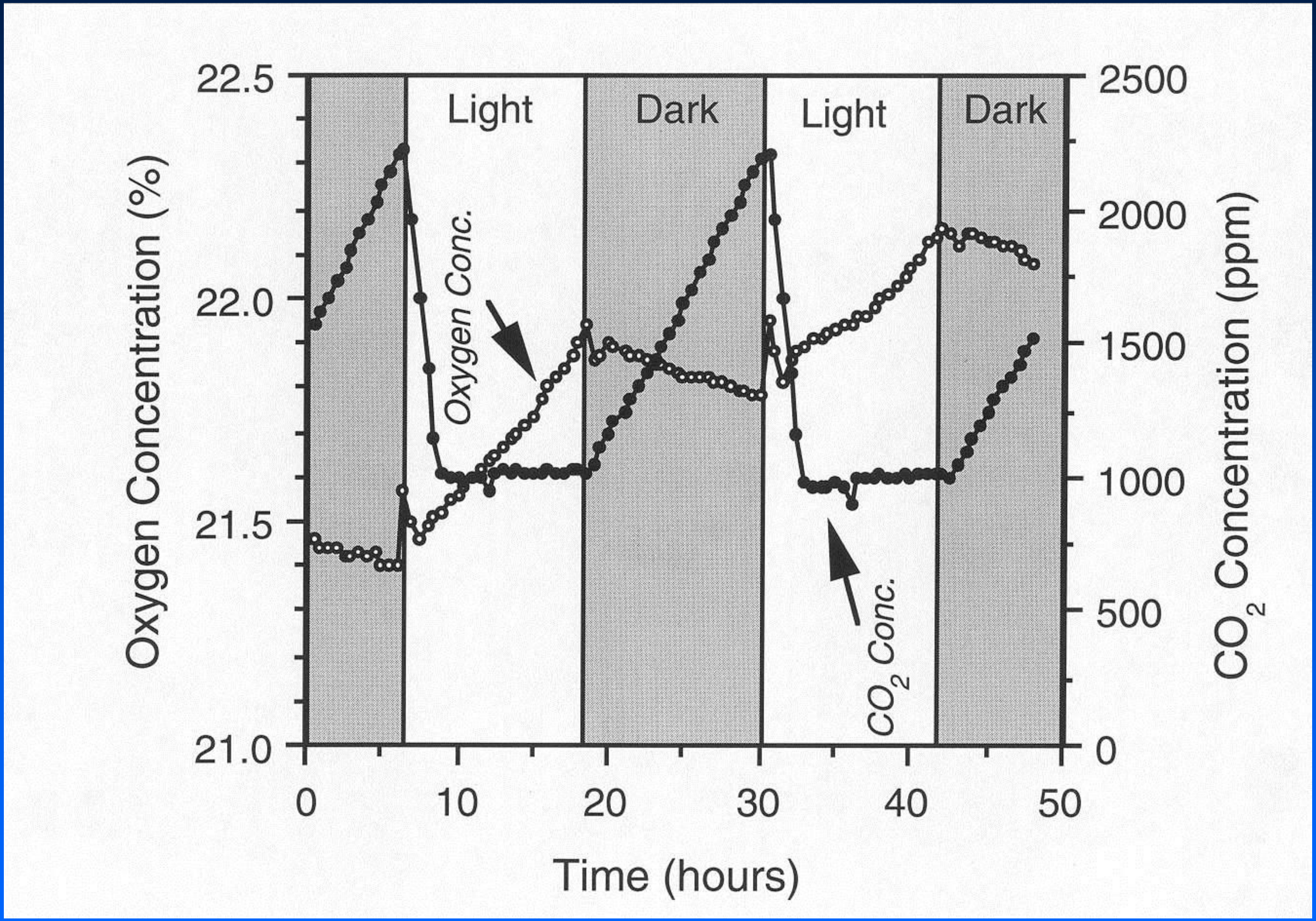




Bubgee, B.G. and F.B. Salisbury. 1988. Plant Physiol. 88:869-878.
Wheeler, R.M., T.W. Tibbitts, A.H. Fitzpatrick. 1991. Crop Science 31:1209-1213.

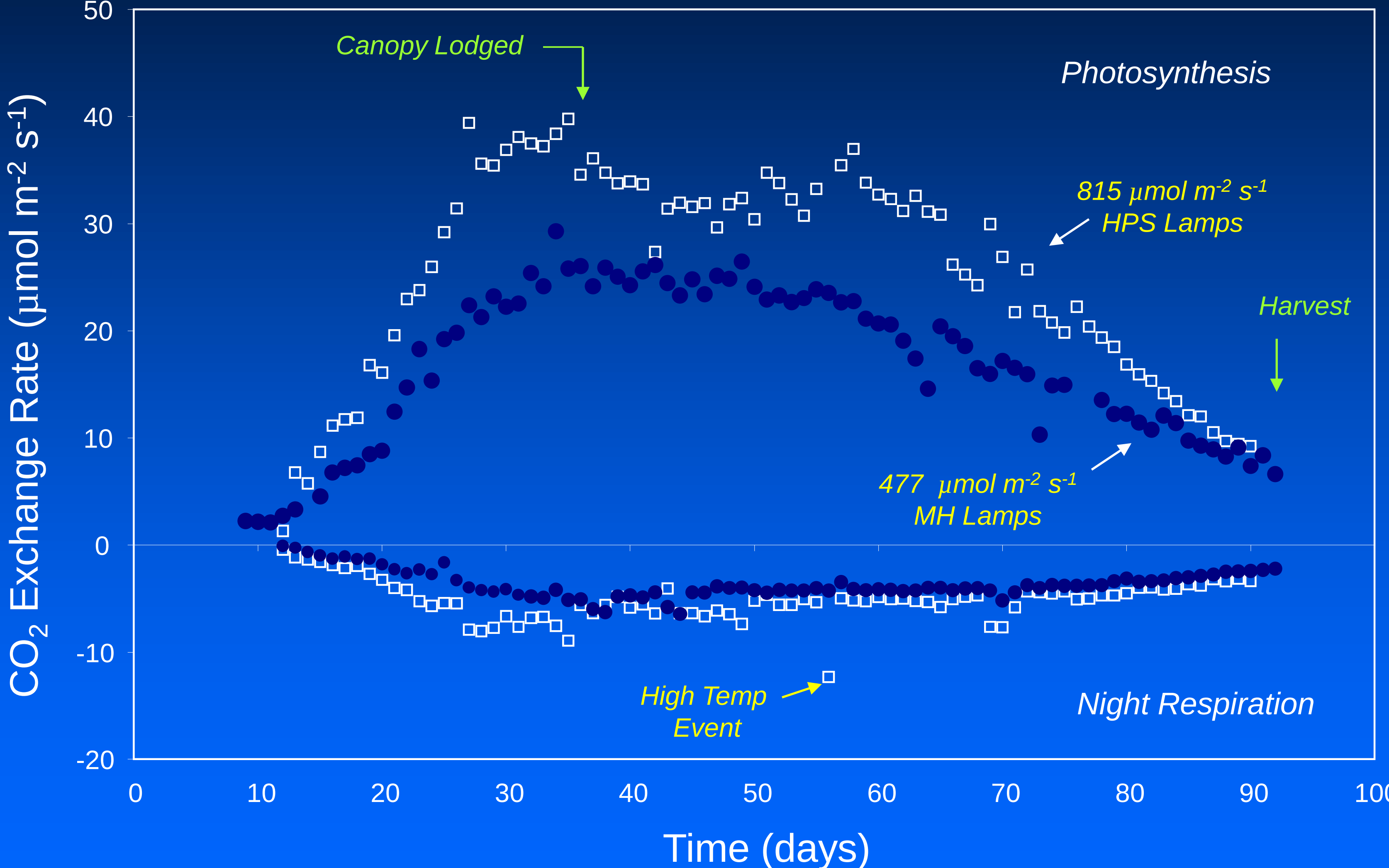
Canopy CO_2 Uptake / O_2 Production

(20 m^2 Soybean Stand)



Wheeler. 1996. In: H. Suge (ed.) Plants in Space Biology.

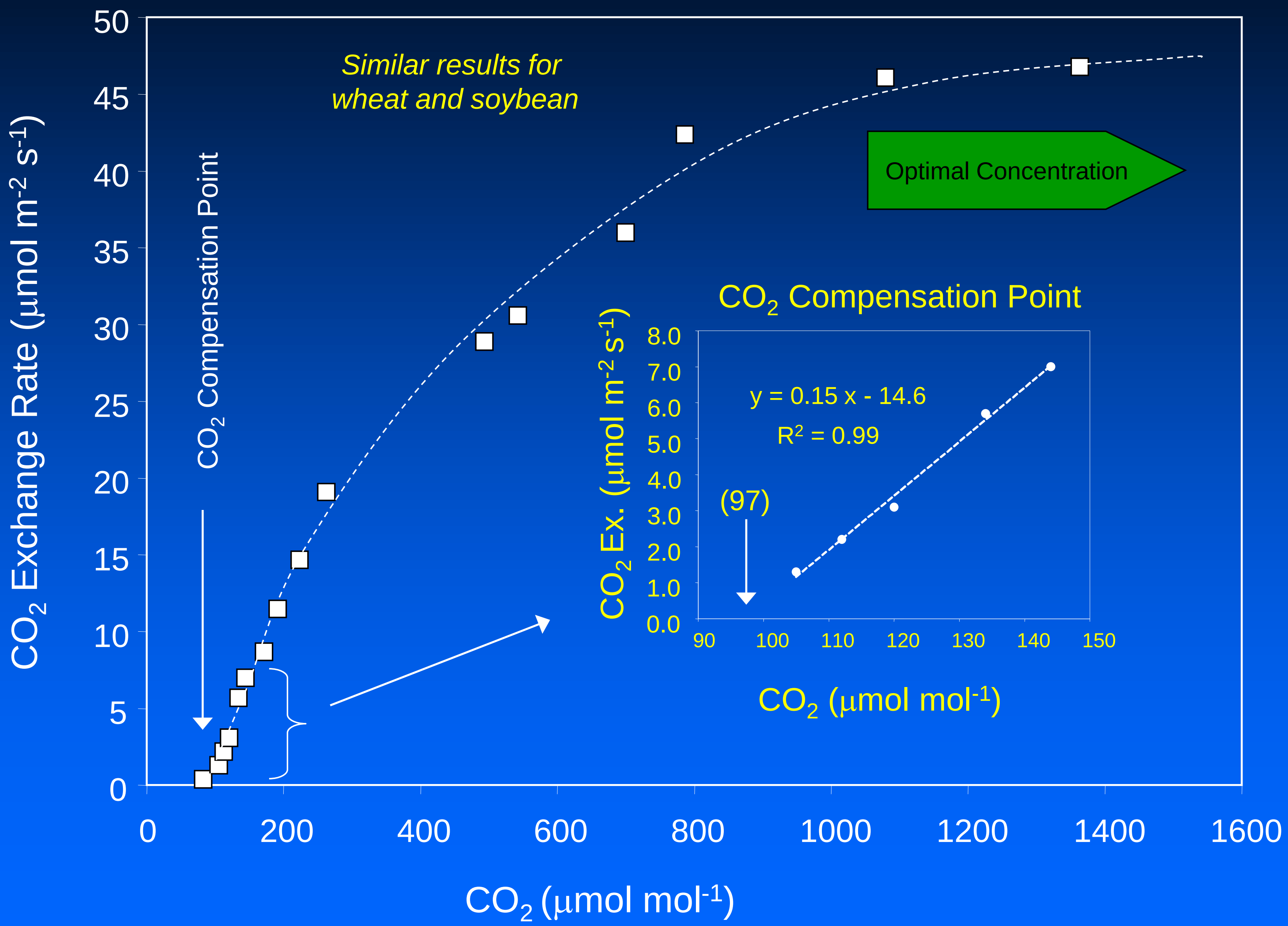
CO_2 Exchange Rates of Soybean Stands



Wheeler et al., 2004. EcoEngineering.

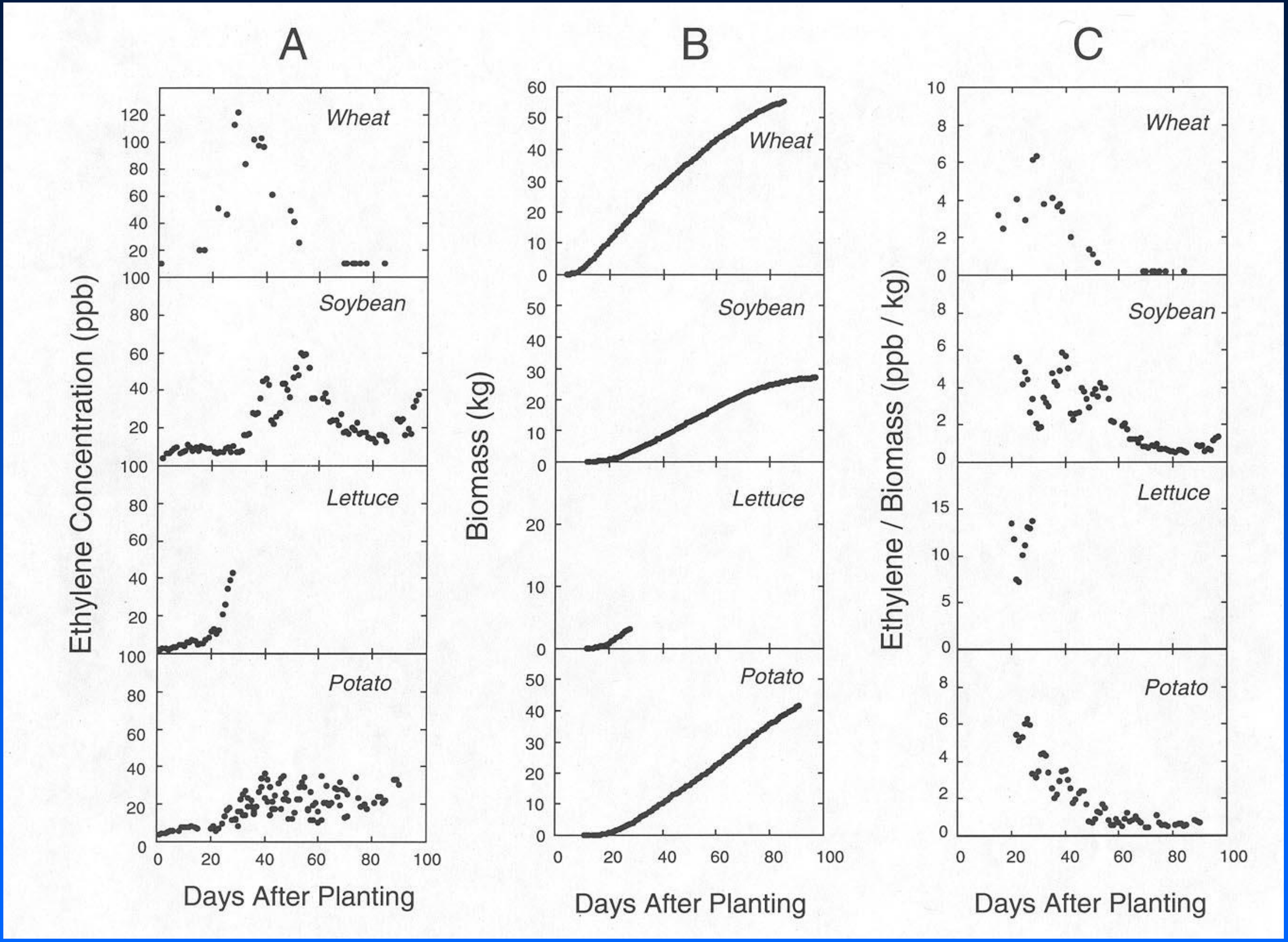
Effect of CO_2 Concentration on Photosynthesis (potato)

Fig. 6



Wheeler. 2006. Potato Research 49:67-90.

Canopy / Stand Ethylene Production



Wheeler et al. 2004. HortScience

Ethylene in Closed Systems

Epinastic
Wheat Leaves
at ~120 ppb

Epinastic
Potato Leaves
at ~40 ppb

(Wheeler et al., 2004 HortScience)

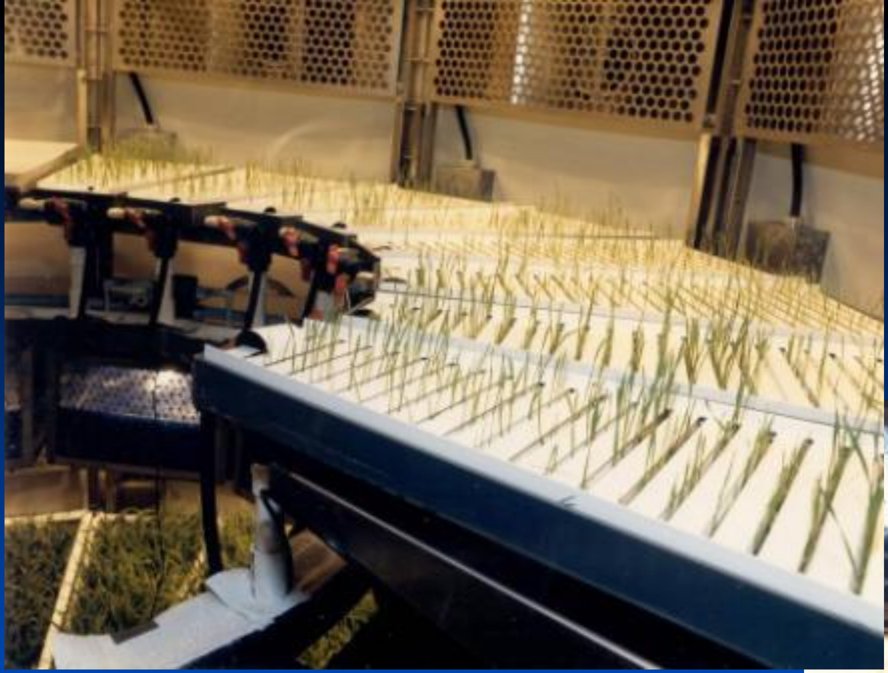
NASA's Biomass Production Chamber (BPC)

Early Vertical Agriculture !

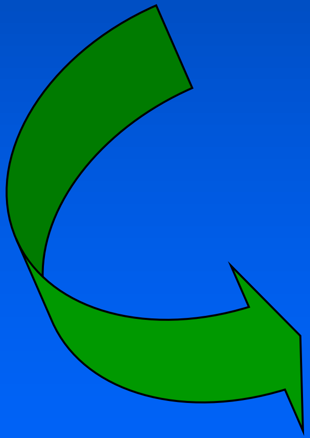
20 m^2 growing area; 113 m^3 vol.; 96 400-W HPS Lamps; 400 m^3 min^{-1} air circulation; two 52-kW chillers

NASA's Biomass Production Chamber (BPC)

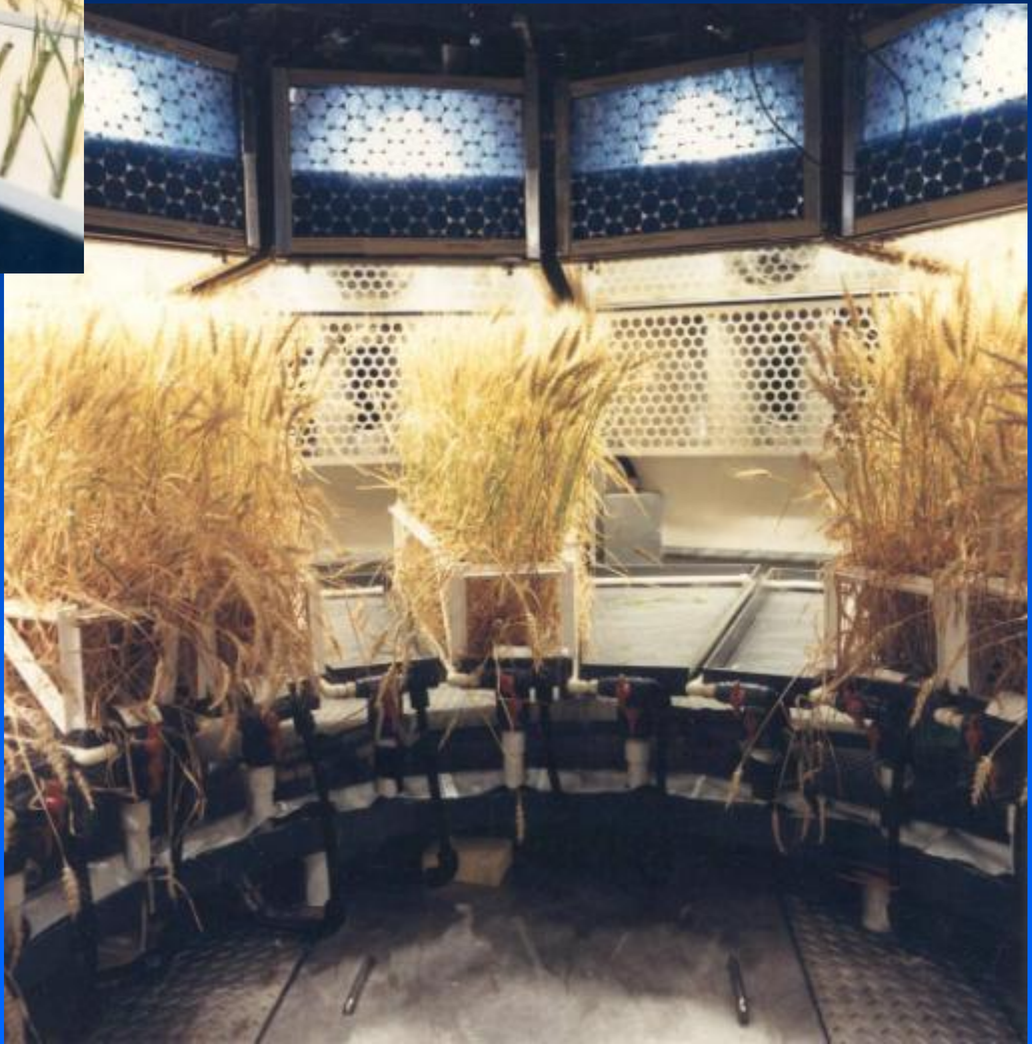
Wheat
(Triticum aestivum)



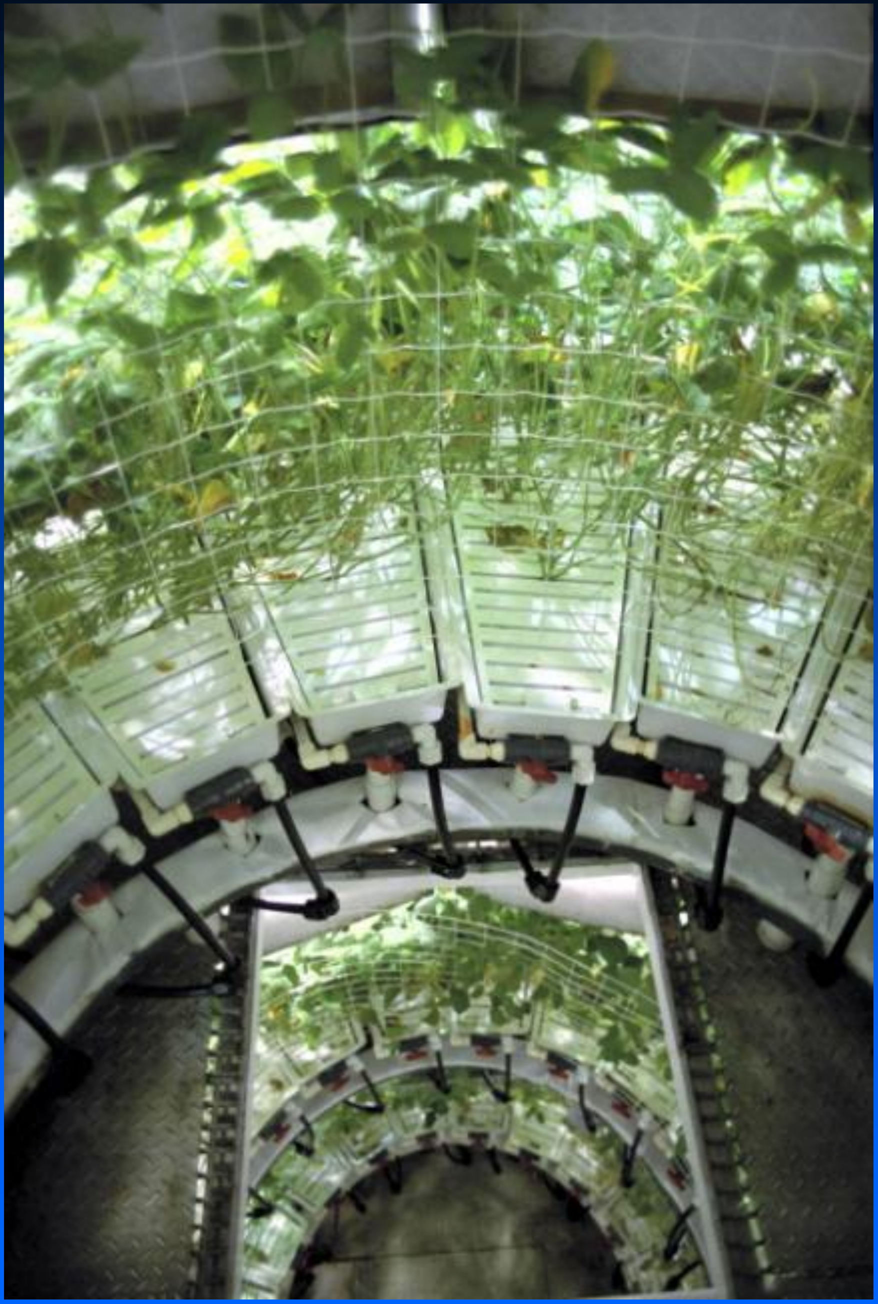
planting

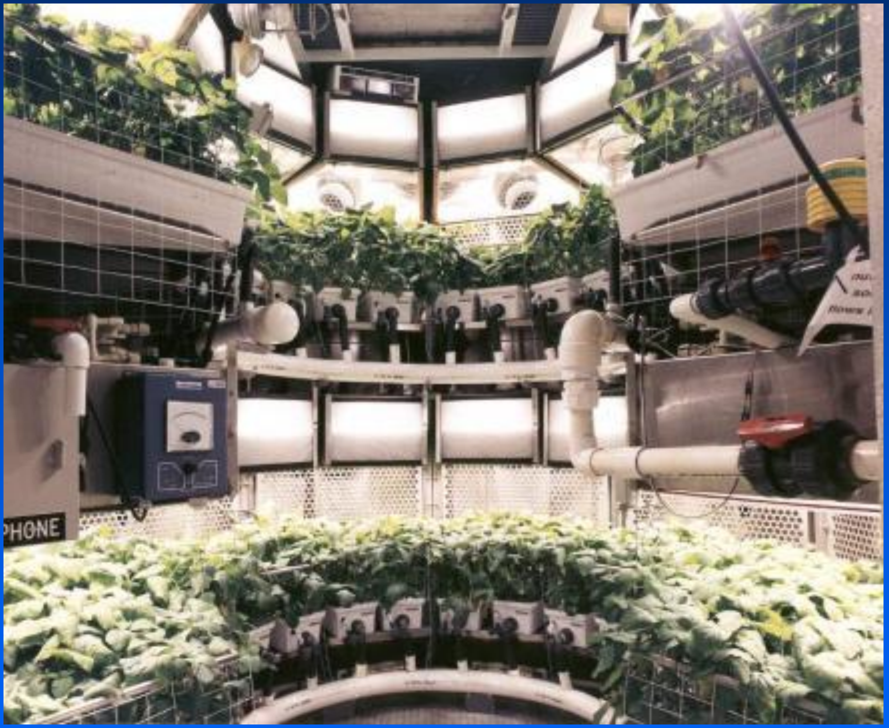


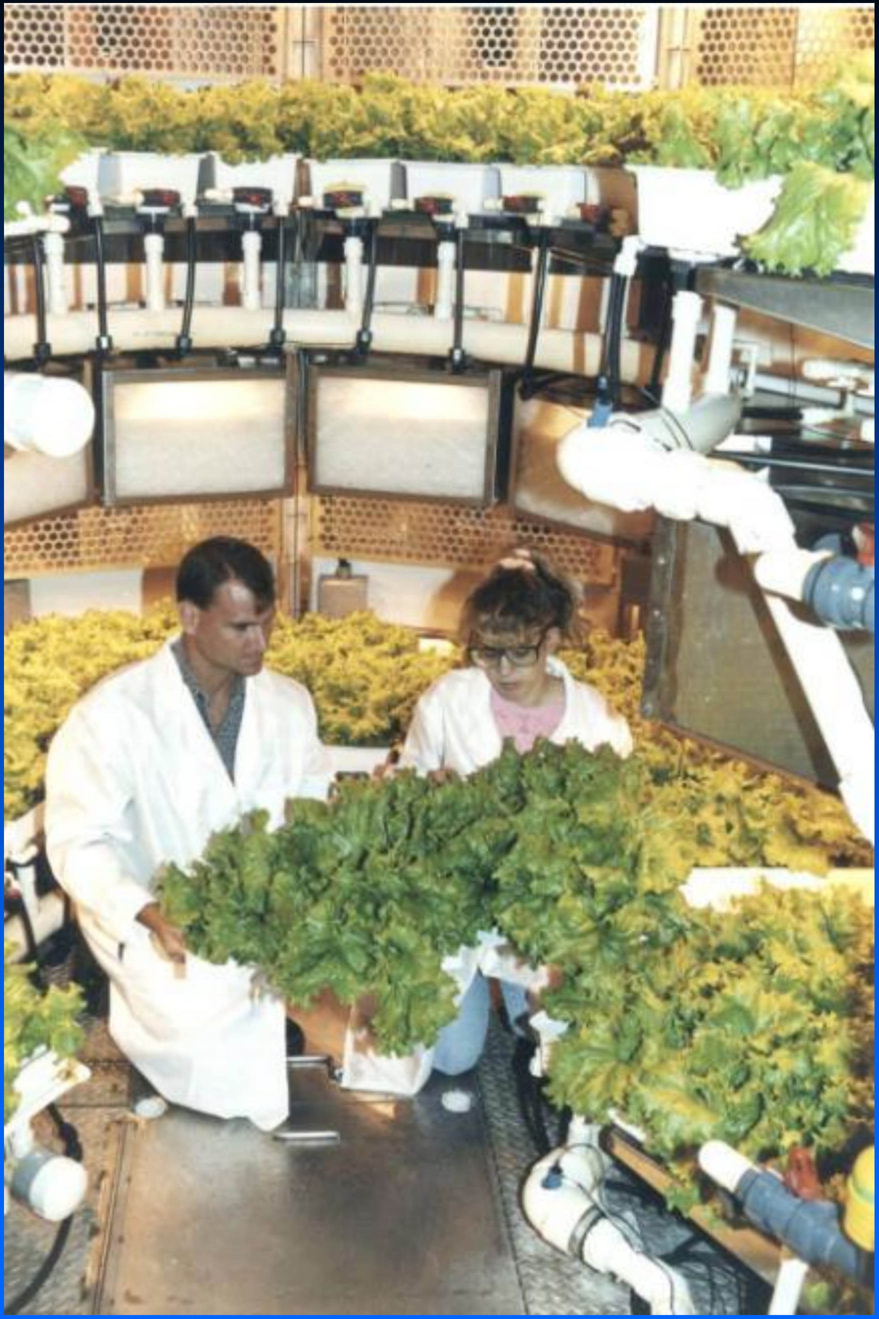
harvest



Soybean
(Glycine max)





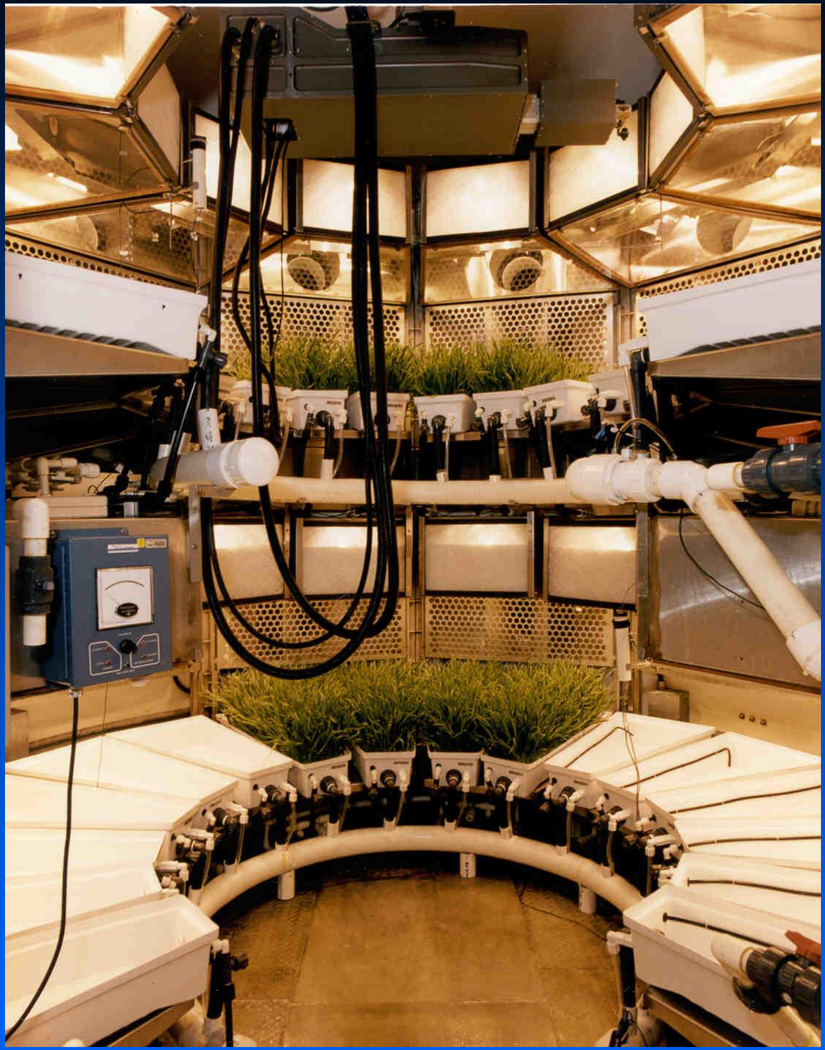


Lettuce
(Lactuca sativa)

Potato

(Solanum tuberosum)

Automation Technologies for CEA



ALSARM Robot in NASA
Biomass Production Chamber

Electric Lighting Considerations

Lamp Type	*Conversion* Efficiency*	*Lamp Life* (hrs)*	*Spectrum*
• Incandescent/Tungsten**	5-10%	2000	Intermd.
• Xenon	5-10%	2000	Broad
• Fluorescent***	20%	5,000-20,000	Broad
• Metal Halide	25%	20,000	Broad
• High Pressure Sodium	30-35%	25,000	Intermd.
• Low Pressure Sodium	35%	25,000	Narrow
• Microwave / RF Sulfur	35-40%+	?	Broad
• LEDs (white)	30-40%	50,000 ?	Broad
• LEDs (red and blue)****	>40%	50,000 ?	Narrow

**   Approximate values.*
***   Tungsten halogen lamps have broader spectrum.*
**** For VHO lamps; lower power lamps with electronic ballasts last up to ~20,000 hrs.*
***** State-of-Art Blue and Red LEDs most efficient.*

Light Emitting Diodes (LEDs)

Red...photosynthesis
Blue...photomorphogenesis
Green...human vision

North American Patent for Using LEDs to Grow Plants Developed with NASA Funding at University of Wisconsin !

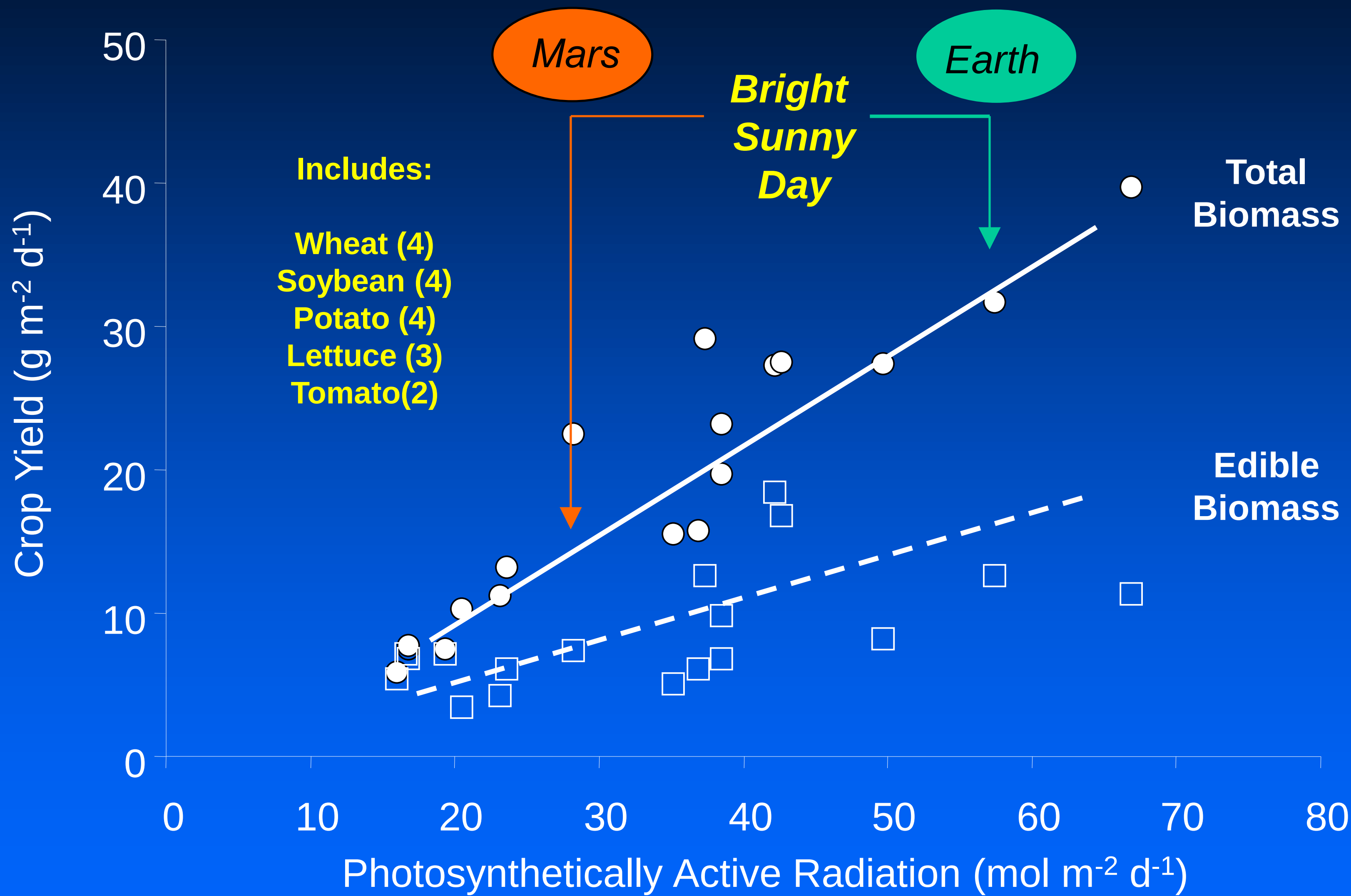
Solar Collector / Fiber Optics For Plant Lighting

2 m^2 of collectors on solar tracking drive (NASA Kennedy Space Center, Florida)

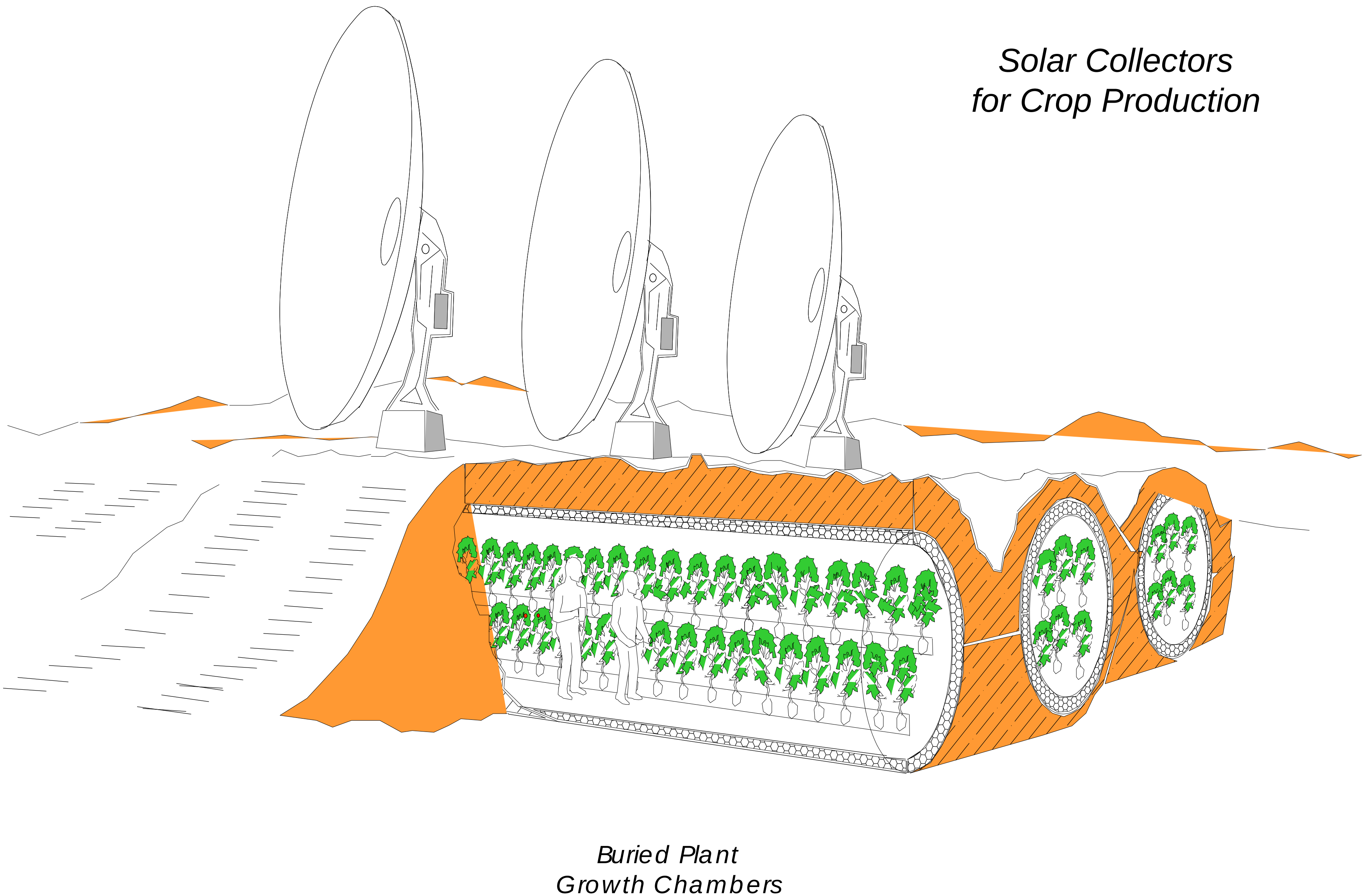
Up to 400 W light delivered to chamber (40-50% of incident light)
Takashi Nakamura, Physical Sciences Inc.

Nakamura et al. 2010. Habitation

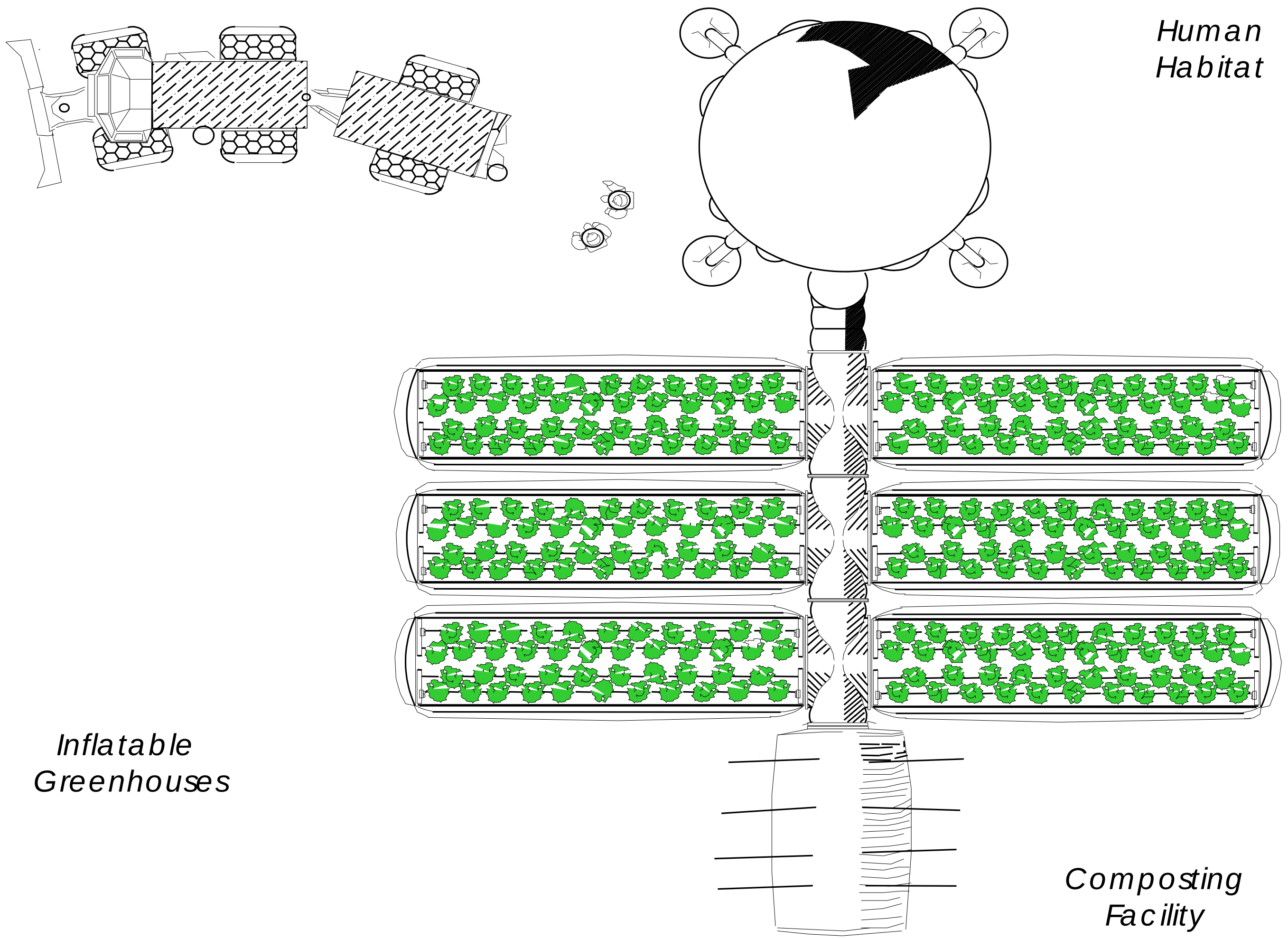
Light and Crop Yield



Wheeler et al. 1996. Adv. Space Res .



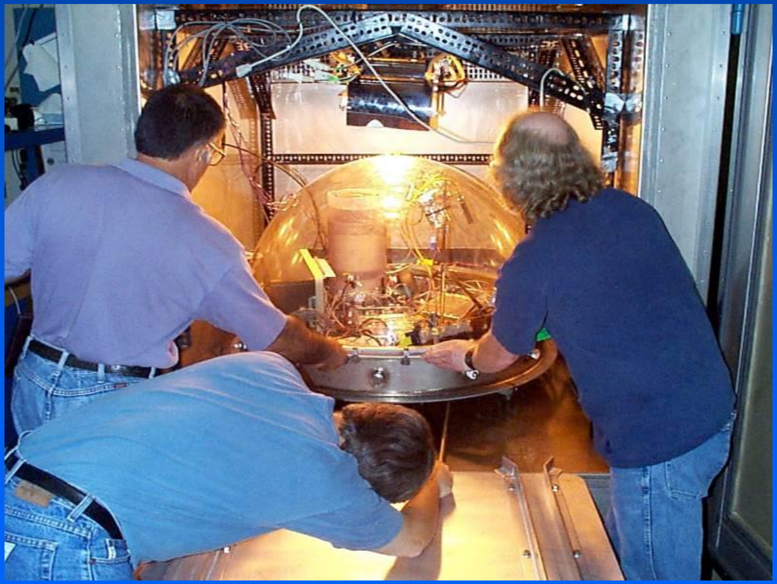
Sadler and Giacomelli, 2002. Life Support Biosphere Sci.



Sadler and Giacomelli, 2002. Life Support Biosphere Sci.

University of Arizona Lunar / Mars Greenhouse

Deployable Mars Greenhouse - Low Pressure Systems



Photosynthetic Radiation at Mars Surface over 2 Martian Years *(J. Clawson, Dissertation 2006)*

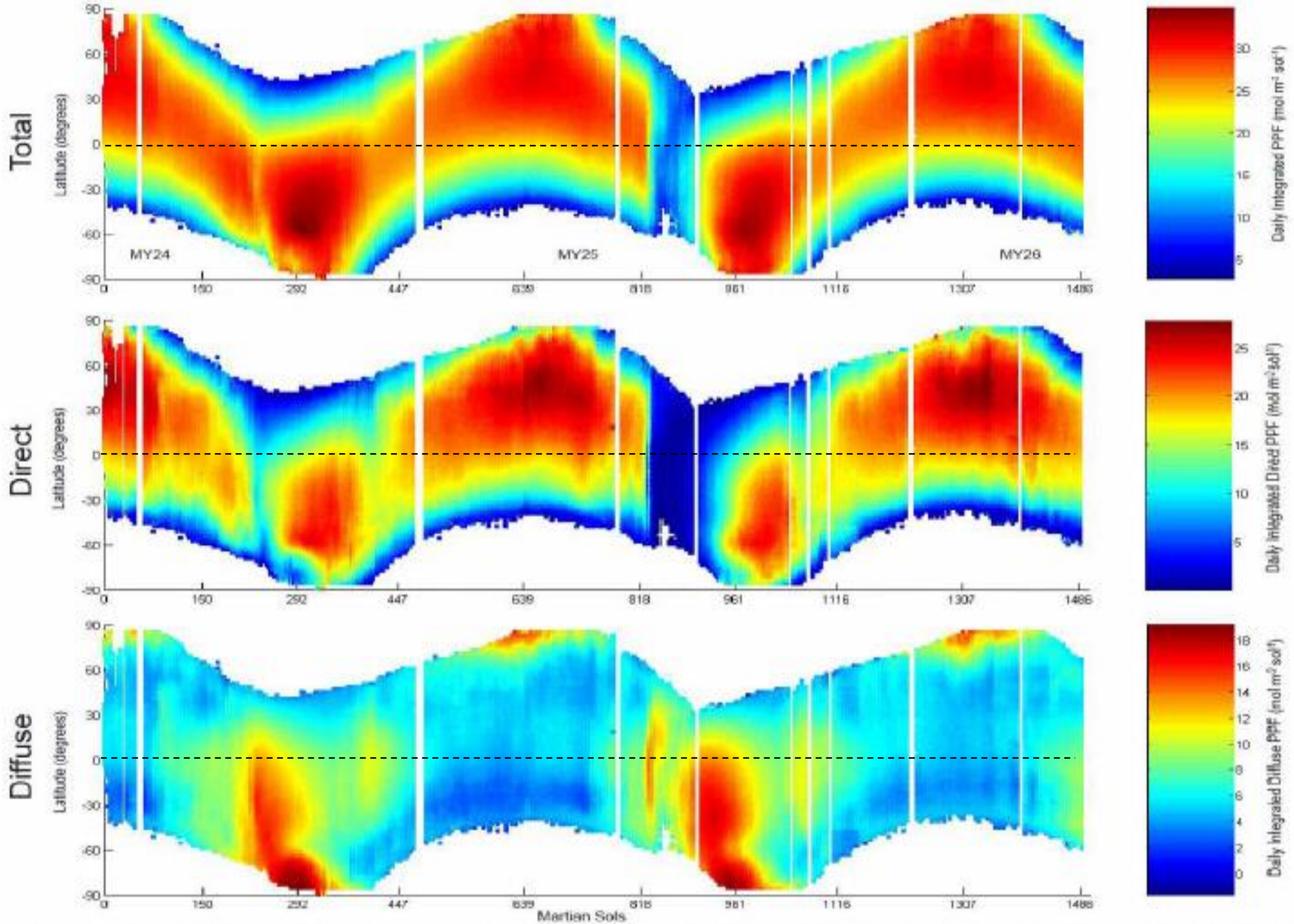


Figure 11 The daily integrated total, direct, and diffuse PPF versus latitude and Martian Sol for two Mars years. The labeled sols correspond to the start of each season on Mars. For example, sol 150 corresponds to the Northern Autumnal equinox.

Hypobaric Testing with Plants

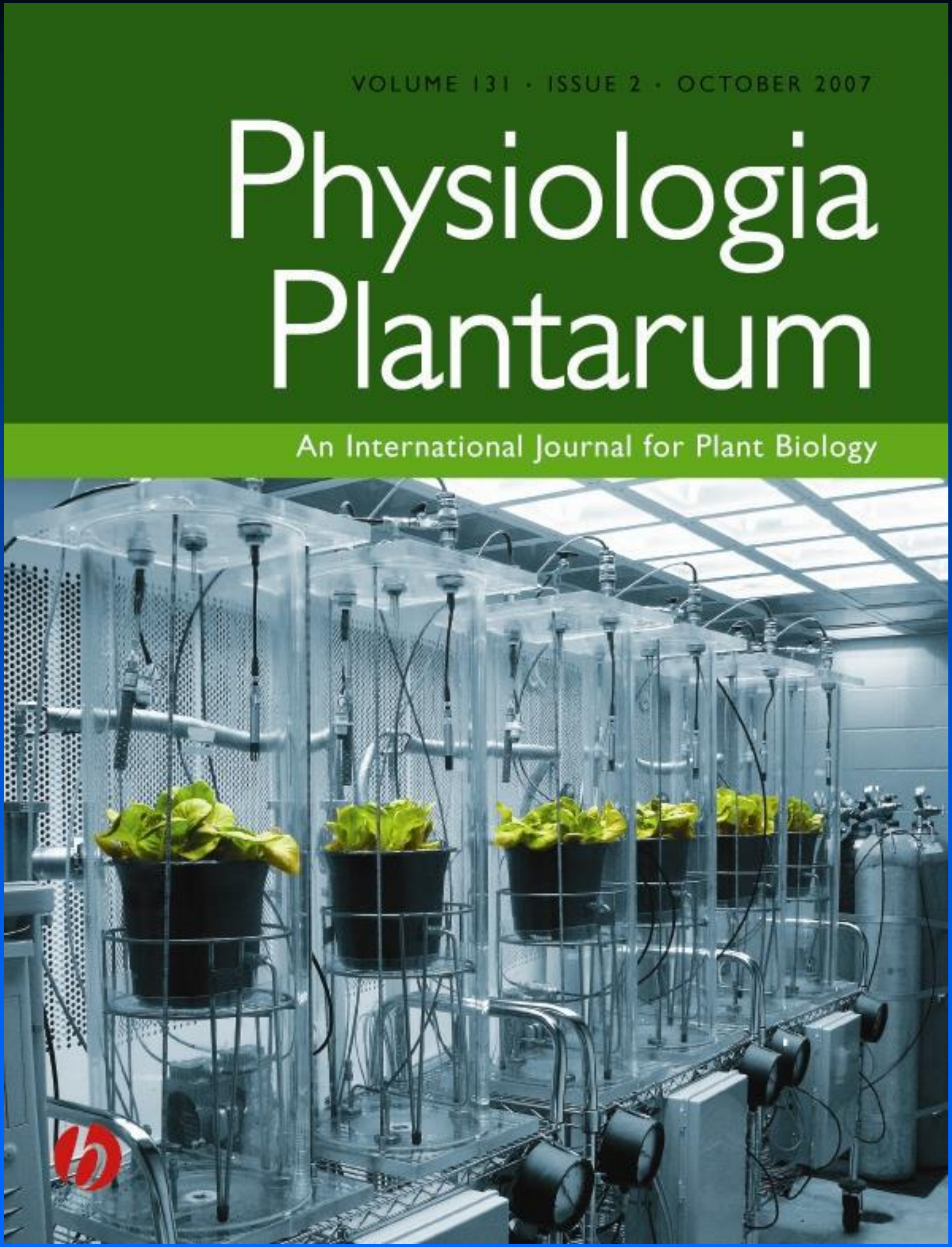
Testing at:

NASA KSC

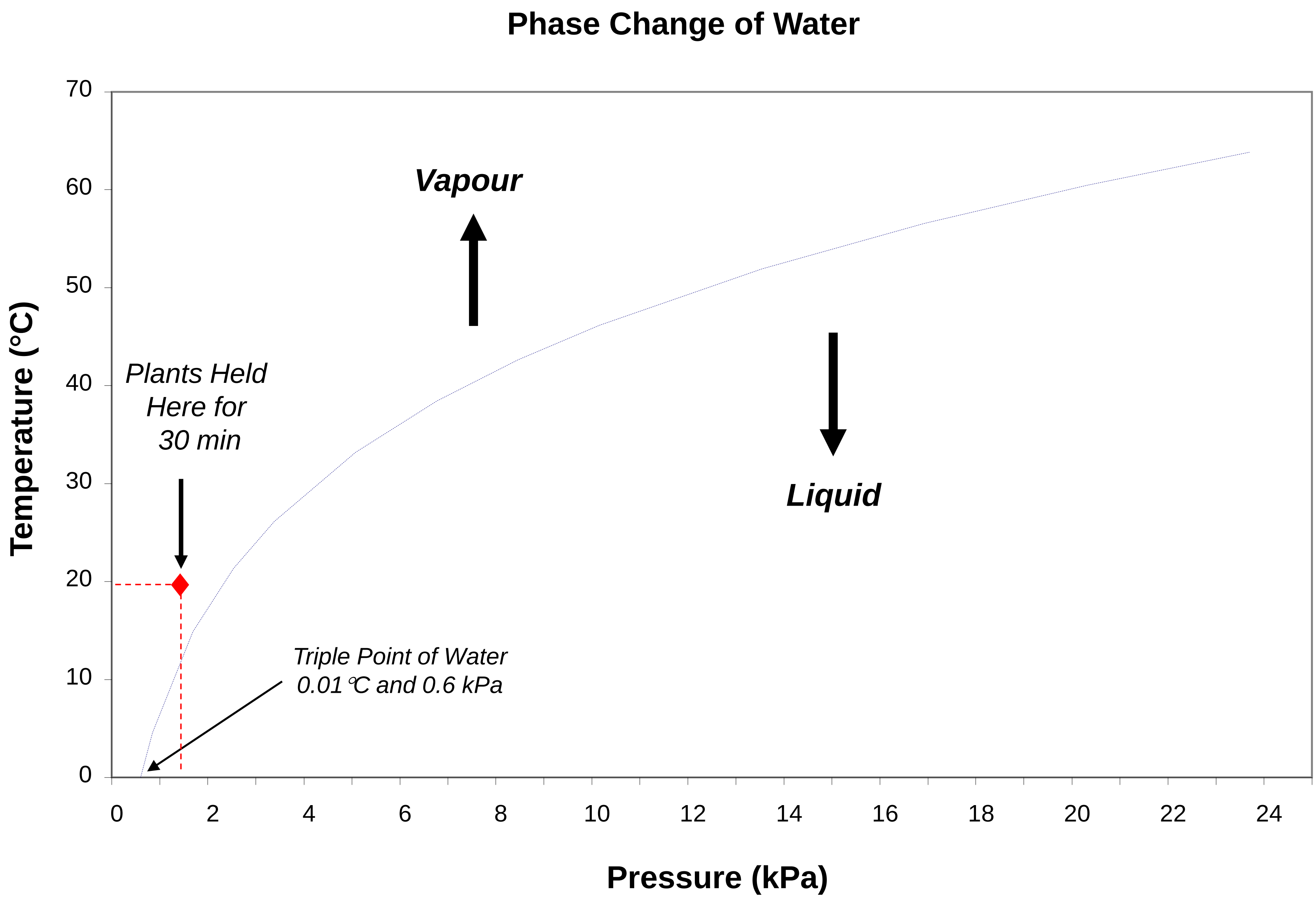
Univ. of Guelph

Texas A&M Univ. ⇒

Univ. of Florida



Lettuce, radish, and wheat plants exposed to rapid pressure drop (27 days old)


Phase Change of Water
Temperature (°C)
Pressure (kPa)
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
20
22
24
Vapour
Liquid
Plants Held
Here for
30 min
Triple Point of Water
0.01 ℃ and 0.6 kPa

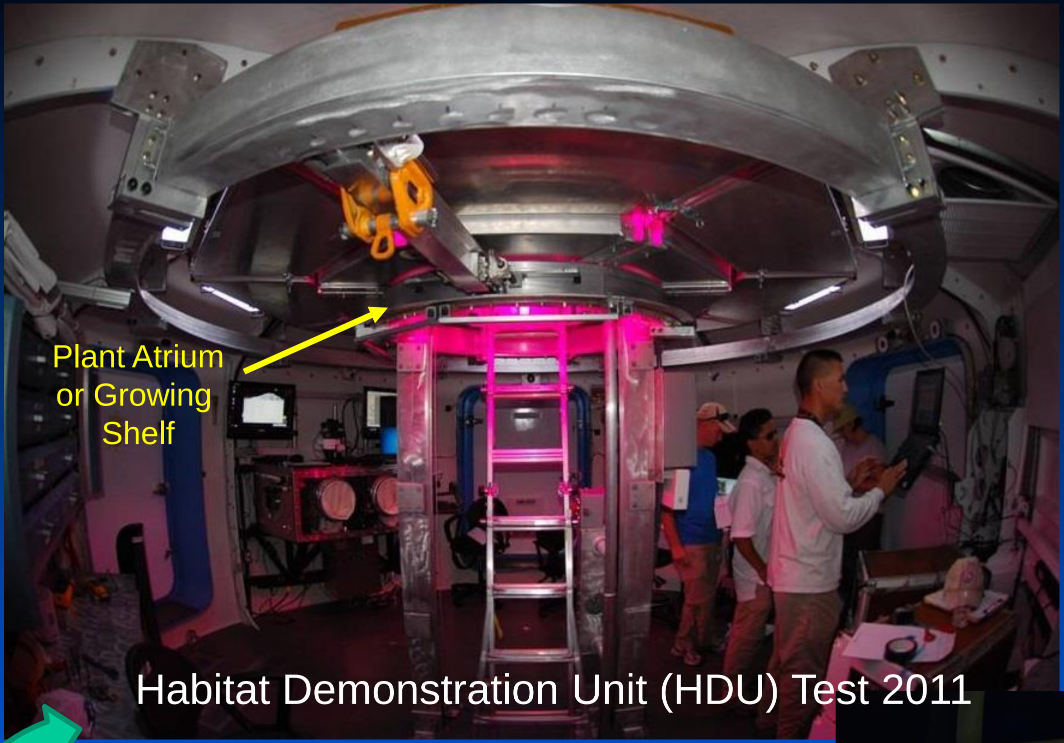
Some other Benefits of Plants in Space

- Fresh Foods to Augment the Diet
  - *Colors*
  - *Texture*
  - *Flavor*
  - *Nutrients*
- Bright Light
- Aromas
- Gardening Activity

Plant Chamber at US South Pole Station

Plants and Human Well-Being

Testing Crops in Human Habitats

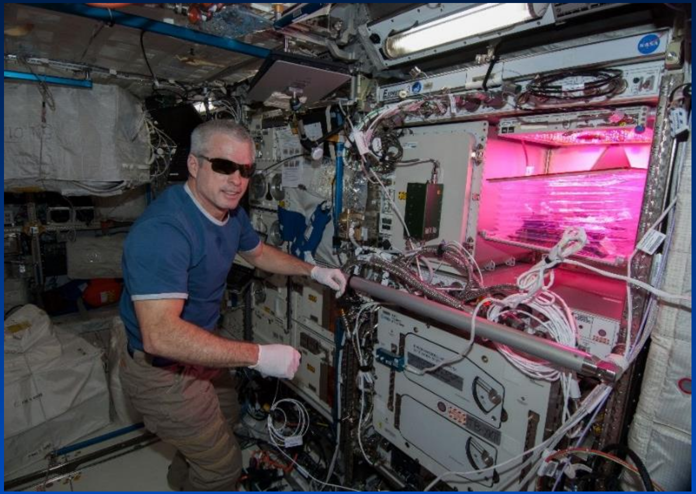


Habitat Demonstration Unit (HDU) Test 2011

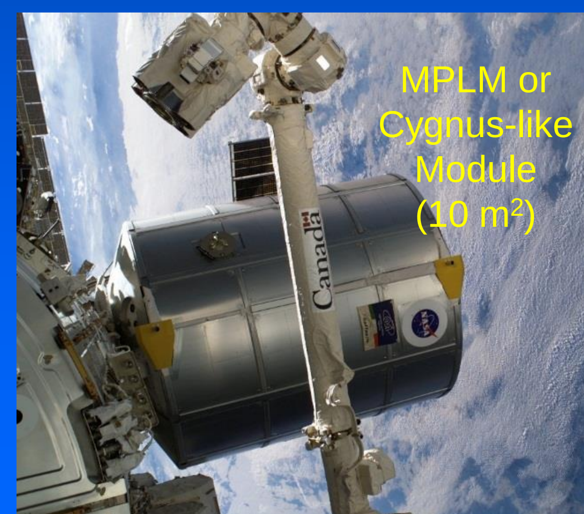

HDU Test 2012

NASA's HDU at Desert Test Site

Plant Testing on the International Space Station—VEGGIE Plant Chamber



Sequential Development for Space Agriculture



Some Lessons Learned from NASA CEA Research

- 20-25 m^2 of crops could provide all the O_2 for one person, and 40-50 m^2 all of the food (dietary energy)
- Better adapted crops are needed—short growth, high harvest index, improved nutrition—Use genetic engineering?
- Lighting is key to sustaining high yields
- CEA systems require large quantities of water (e.g., 5 L m^{-2} d^{-1}) and this water must be recycled.
- Up to 90 kg of fertilizer would needed per person per year, emphasizing the need for recycling nutrients.
- Plants can provide psychological benefits to humans—this needs further study.
- The use of plants for life support will likely evolve sequential, starting with small, supplemental food production and expanding for future missions.

Plants and Living in Space

As we explore sustainable living for space, we will learn more about sustainable living on Earth

KSC Advanced Life Support Team, Hangar L, KSC 1994

One of our Kennedy Space Center Researchers !

Michelle McKeon-Bennett, 2004, Space Life Science Laboratory, KSC, Florida

Effect of Light on Productivity and Crop Area Requirements